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Effect of Er,Cr:YSGG laser surface conditioning on the adhesion of fiber reinforced composite and zirconia intraradicular posts to the root dentin

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Short title: *Effect of laser conditioning on root posts to dentin*

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Abstract: This study evaluated the influence of Er,Cr:YSGG laser surface conditioning on push-out bond strength of different root posts to the root dentin. Extracted (N=27, n=9 per group) and endodontically treated human mandibular premolars were prepared to receive the posts. Three types of posts, namely quartz fiber (D), glass fiber (S) and zirconium dioxide post (C) were luted with resin cement. The posts were randomly assigned to one of the surface conditioning method: a) No conditioning, control (L0), b) Er,Cr:YSGG laser at 175 mJ, 3.5W for 60 s, with 60 μs pulse duration and repetition rate of 20 Hz (L1) and c) at 225 mJ, 4.5W for 60 s, with 60 μs pulse duration and repetition rate was 20 Hz (L2) irradiation. Six sections (two coronal, two middle, and two apical) were made in each tooth yielding to 1 mm thick specimens. The specimens were stored in distilled water at 37°C for 24 h and push-out bond strength (MPa) was tested in a Universal Testing Machine (1 mm/min). Data were analysed using Kruskall-Wallis and Dunns`s post hoc tests (α=0.05). In group D, both laser treated groups (L1:16.16±19.89; L2:8.24±9.26) presented significantly less bond strength compared to control group (L0:28.3±16.8) (p<0.001). Mean push-out bond strength values did not significantly differ according to the root segments (coronal, middle, and apical) (p=0.106). Application of Er,Cr:YSGG laser, with the parameters tested, did not increase the bond strength of zirconium glass fiber and zirconium oxide posts. Laser surface conditioning decreased the bond strength of quartz fiber posts in the root canal.

Keywords: *Adhesion, bond strength, Er,Cr:YSGG laser, fiber post, zirconia post*

Introduction

Endodontically treated tooth with insufficient coronal structure is often restored with crowns. In the presence of insufficient dentin, post-core restoration is required to provide retention and support to the crown [1]. As a result of unfavourable colour of metal posts, such as a grayish shine through under the translucent ceramic crowns, around and through the surrounding gingiva [2], tooth coloured root post systems have gained attention for aesthetic reasons [3].

Among different root post options, fiber reinforced composite resin (FRC) post systems demonstrate successful clinical performance [4]. FRC posts increase the transmission of light within the root [5] and having low modulus of elasticity [6] they reduce the risk of root fracture [7] and eliminate corrosion related problems [8]. Typically, FRC posts are made of carbon, quartz, or glass fibers, embedded in a matrix of epoxy or methacrylate resin [9,10]. On the other hand, zirconium dioxide (ZrO_2) posts are partially stabilized with 3-6% yttrium oxide (Y_2O_3) and exhibit a polymorphic structure with monoclinic, tetragonal, and cubic crystalline phases [11]. High flexural strength, high fracture toughness, chemical stability, biocompatibility and favourable optical properties are advantages of zirconia as a restorative material [10]. Zirconia posts demonstrate high fracture resistance due to their high flexural strengths that is comparable to that of cast gold posts and cores or titanium posts [12].

Clinically, cementation failure and root fracture are the main problems affecting the survival of post systems [3]. In order to overcome this problem, surface conditioning of the post [13] and roughening the dentinal surfaces of the root canal are suggested increasing the retention of the posts [14]. In addition, selection of an appropriate adhesive system is critical for the success of FRC post. In that respect, achieving a chemical and micromechanical adhesion of the luting agent to both the post and the root canal dentin is essential [6].

Given the potential of some lasers, such as the neodymium: yttrium aluminum garnet (Nd:YAG), erbium (Er):YAG lasers to alter the dentin morphology, they may influence the adhesion of the posts to the root canal dentin [15,16]. Recently, lasers have been shown to provide relatively safe and easy means of altering the surface of various dental materials [17]. Many of the technological advances have been directed at the use of lasers in clinical settings as an alternative to acid etching of dental materials or teeth for improving bond strength [18]. Laser application was stated as an alternative treatment to other surface conditioning methods for enhancing the bond strength of the dental materials to metal surfaces [19,20]. The use of several laser types such as Nd:YAG, Er:YAG [21], erbium, chromium: yttrium, scandium, gallium, garnet (Er,Cr:YSGG) [22] and carbon dioxide (CO_2) lasers have been studied also for dental applications [23]. Er:YAG and Er,Cr:YSGG lasers have essentially similar basic properties apart from slight differences in terms of laser wavelength in the range of available pulse durations and in energy [24]. The use of pulsed erbium lasers, such as Er:YAG and Er,Cr:YSGG lasers has been considered for surface conditioning where the latter with 2.78 μm wavelength has been used for conditioning porcelain brackets, indirect resin composites, leucite- or alumina-based ceramics [25]. High-intensity lasers have been recently investigated in order to increase the surface roughness of ceramic restorations, favouring adhesion of resin-based luting cements to ceramic surfaces through micromechanical interlocking [26]. The laser surface conditioning also alters the wettability characteristics of ceramics for improved adhesion and bonding [27]. Although Er,Cr:YSGG laser surface conditioning at 3 W output was found to increase adhesion of resin cements to zirconia [28], its effect on adhesion of glass and quartz fiber posts and eventually their bond strength to dentin surfaces is still unknown.

The objectives of this study therefore were to evaluate the effect of Er,Cr:YSGG laser surface conditioning operating at different parameters on the retention of FRC and zirconia posts in the root canal at different regions of the root compared to no conditioning. The null hypothesis tested were that a) Er,Cr:YSGG laser conditioning would not increase push-out bond strength of FRC and zirconia posts to dentin surfaces and b) the results would not be significantly different at coronal, middle and apical parts of the root.

Materials and Methods

The brands, manufacturers, chemical composition and batch numbers of the materials used in this study are listed in Table 1.

Tooth selection

Extracted human mandibular premolar teeth (N=27, n=9 per group) were obtained. All teeth were single rooted with a single canal, which was confirmed with multiple angulated radiographs. The soft-tissue remnants and calculi on the external root surface were removed mechanically using hand instruments. The crowns were removed at the cement-enamel junction with a diamond disc (Komet, Lemgo, Germany) under water-coolant at low speed to obtain a standardized root length of 15 mm.

Root canal treatment

The working length of each root canal was established 1 mm short of the apical foramen. The root canal instrumentations were performed by single operator using ProTaper rotary instruments (Dentsply, Maillefer, Ballaigues, Switzerland) to the size of F3. The teeth were irrigated with 2 ml of 2.5% sodium hypochloride after each instrument. Final irrigation was performed using 5 ml 17% EDTA, 5 ml 2.5% NaOCl and 5 ml distilled water, respectively. After drying, all root canals were obturated with matched tapered single-cone gutta-percha and AH 26 (Dentsply De Trey, Konstanz, Germany) sealer.

Post types and surface conditioning methods

Three types of post systems were used in this study, namely a) quartz fiber (D: D.T. Light post (#2), Bisco Inc, Schaumburg, Illinois USA), glass fiber (S: SnowPost (#16), Abrasive Technology, OH, USA) and zirconium dioxide post (C: CosmoPost (r: 1.7 mm), Ivoclar Vivadent AG, Schaan Liechtenstein).

The posts were randomly assigned to one of the following laser surface conditioning method:

Group L0: No conditioning was performed in this group and acted as the control group.

Group L1: The post surfaces were conditioned using Er,Cr:YSGG laser (Waterlase; Biolase Technologies, San Clemente, CA, USA) at 175 mJ, 3.5 W for 60 s, with 60 μs pulse duration and repetition rate of 20 Hz. The surfaces were irradiated from 1 mm distance on a fixed apparatus with 75% water and 85% air-cooling.

Group L2: In this group, were conditioned using Er,Cr:YSGG laser (Waterlase) at 225 mJ, 4.5 W for 60 s, with 60 μs pulse duration and repetition rate was 20 Hz. The surfaces were irradiated from 1 mm distance on a fixed apparatus as described in Group L1.

After storage in saline solution for 7 days, gutta-percha was removed with drills to a length of 10 mm. The root filling was removed with the same drill as deep as necessary for each post to be inserted until the two-thirds of the root length. The post space for each post was prepared with the matching drill of the post system. The same size posts were luted with dual polymerized resin cement (Panavia F 2.0, Kuraray Noritake Dental Inc., Osaka, Japan), according to the manufacturer's instructions. Excess cement was then removed with a scaler.

Push-out test

Each root was sectioned perpendicular to its long axis to obtain 1 mm thick specimens with a slow-speed diamond saw (Buehler Ltd., Lake Bluff, IL, USA) under water coolant. Altogether, 198 sections were obtained from each tooth of which 77 were from the coronal, 64 from middle and 57 from apical regions of the roots. The specimens were stored in distilled water at 37°C for 24 h in an incubator until tests.

Push-out test was performed using a cylindrical plunger mounted on the Universal Testing Machine (Instron, Canton, MA, USA). Compressive load was applied at a crosshead speed of 1 mm/min until the post segment was dislodged from the root to the apical aspect in the apical-coronal direction. The plunger tip size was selected and positioned to contact only the post, without stressing the surrounding root canal walls.

The initial bond strength result (MPa) was calculated dividing the maximum load (N) by the area of adhesion surface (mm^2). The adhesion area of each section was computed as the area of the lateral surface of a cone, using the formula:

$$Sl = \pi(r + R)a$$

where π = 3.14, R is the coronal radius, r is the apical radius, a is the apothem, computed using the formula:

$$a = [h^2 + (R - r)^2]^{1/2}$$

where h is the thickness of the slice.

One post from each group was randomly selected for scanning electron microscopy (SEM) (Quanta 400F, FEI, Oregon, USA) evaluation. The SEM photomicrographs were obtained at x150 and x1000 magnification.

Statistical analysis

Statistical analyses were performed with SPSS 19.0 software (SPSS Inc., Chicago, IL, USA). Distribution of data was assesed using Shapiro-Wilk test. The means of each group were analyzed by Kruskall-Wallis and Dunns`s post hoc tests with push out bond strength (MPa) as the dependent variable and post type (3 levels: quartz fiber, glass fiber, zirconia), surface conditioning with laser (2 levels: L1 versus L2) and root level (3 levels: coronal, middle, apical) as the independent factors. P values less than 0.05 were considered to be statistically significant in all tests.

Results

Push-out bond strength results (MPa) were significantly affected by the post type ($p<0.001$), laser surface conditioning ($p<0.001$), but not the root level ($p>0.001$).

While with the post type D, control group (L0) showed significantly higher results compared to both laser conditioning (L1 and L2) ($p<0.001$) (Table 2), with the post type S, no significant difference was found between the laser-conditioned (L1 and L2) and control groups (L0) ($p=0.057$). In Group C, L1 and L2 increased the bond strength yet being not significantly different compared to the control, L0 ($p=0.158$).

The push-out bond strength values did not vary significantly according to the root segments including coronal, middle, and apical (Table 3).

SEM images presented some irregularities on C type of posts but large defects and cracks were evident in post types D and S, respectively after the laser conditioning methods (Figs.1-3-a-f.)

Discussion

This study evaluate the effect of Er,Cr:YSGG laser surface conditioning at different operational parameters on the retention of FRC and zirconia posts in the root canal at different regions of the root compared to no conditioning. Based on the results of this study, since application of Er,Cr:YSGG laser did not increase the push-out bond strength and no regional difference was observed, the null hypothesis could be accepted.

Since the long-term success of endodontically treated tooth is dependent on the ability of the post to resist the chewing forces [5], retention of the post becomes an important factor for the success of the restoration [29]. Composition of the FRC post affects the bond strength of resin-based luting agent to the post [25]. Therefore, two different FRC and a zirconia post were selected. When the post compositions were considered, glass fiber and quartz fiber posts demonstrated higher bond strength than zirconia ceramic post [3,31]. The higher push-out bond strength of the FRC groups could be attributed to the superior adhesion between the methacrylate resin matrix of the fiber post and the methacrylate-based adhesives and resin cement also weaker bonding affinity of the resin cement to the ceramic posts [32,33].

In this study, dual polymerized resin cement was used to lute the posts in the root canal. Photo-polymerization from the top of the post coronally, is not sufficient to polymerize the photo-polymerized adhesives and resin cements optimally. For this reason. dual-polymerized or chemically-polymerized resin cements were recommended for the cementation of fibre posts [34]. Adhesive resin cements, such as Panavia F2.0 used in this study, contains 10-

Methacryloyloxydecyl dihydrogen phosphate (10-MDP) functional monomer. This monomer can establish favourable adhesion to both the dental tissues and the metal oxides or zirconia [35]. The results in this study did not differ significantly in the coronal, middle and apical regions of the root. Consequently, it can be stated that the resin cement used, presented similar levels of polymerization even in the most apical parts of the roots, regardless of the post type.

Adhesion of resin-based materials to dental materials after laser application is highly affected by ablation parameters such as the duration, frequency and power of irradiation [36]. The output power of Er,Cr:YSGG laser can vary from 0 to 6 W [37]. Various output values were evaluated for dental use ranging from 0.5 to 1 W, 3 to 4.5 W and 6 W [38, 39]. In the present study, high output values were tested since the laser was applied to the post surfaces that were not in contact with dental tissues. In a similar study, Er:YAG laser was tested on quartz fiber post and no significant effect was observed on the push-out bond strength compared to the control group [6]. Likewise, in the present study, no significant difference was found in S group that consisted of zircon-glass fiber. Interestingly, in laser treated D group, the push-out bond strength values were even less than those in the control groups. The surface analysis in this group presented large defects possibly affecting the wettability of the resin cement on the methacrylate matrix of the FRC post. In this study, no chemical analysis was made but whether laser conditioning decomposes the methacrylate groups and free radicals on the post surface or not needs further investigation.

Miranda et al. [36] evaluated the surface roughness on ZrO_2 surfaces after Er,Cr:YSGG laser irradiation at 1.5 W/20 Hz with air-water cooling proportion of 80/25% and reported that laser irradiation decreased the surface roughness. Previous studies in this regard showed controversial results [20,37,40]. One reason for this could be the different methods employed for roughness measurements. In the present study, 3.5 and 4.5W laser application did not increase the bond strength significantly. SEM analysis revealed that Er,Cr:YSGG laser application resulted in irregularities on the surface of zirconia post. In addition, untreated specimens showed more flat surfaces than laser treated specimens. Due to the round nature of the posts, surface roughness is difficult to measure in a predictable way. Future studies should correlate roughness with the bond strength results.

Kurt et al. [41] investigated the effects of Er:YAG laser at different power settings on the push-out bond strength of resin composite core materials on glass fiber posts. Unfortunately, Er:YAG laser application significantly decreased the bond strength of cores to fiber posts compared to the untreated group. The reason for such results was attributed to the damage on the surface as a result of heat. Similarly, in the present study with comparable number of specimens, the lowest mean push-out bond strength values for quartz fiber post was recorded with the highest power setting of Er,Cr:YSGG. On the other hand, when evaluating the effect of Er,Cr:YSGG laser on bond strength between zirconia ceramic and resin cement, 3W output power has been reported to be sufficient for roughening the zirconia surface and establish improved bond strength of resin cement [28]. SEM findings indicated a smother surface on the zirconia posts but higher bond strength results, still being not significant compared to the control group. This could be explained with more reliable chemical polymerization of 10-MDP functional monomer of the resin cement on zirconia [42].

The laser application on the post surface has gained attention as a current approach. Er,Cr:YSGG with two different power settings was used in this study. The type of laser, energy parameters and ablation rates may yield to different results in the treatment of post surfaces. Limited output values, the use of single laser type, and selected posts could be expanded in further studies considering other laser types and energy parameters on larger sample size.

Conclusions

From this study, the following could be concluded:

1. The application of Er,Cr:YSGG laser with the studied parameters did not increase the push-out bond strength of glass, quartz fiber or zirconia root posts. Laser application even decreased the results in quartz fiber post group.
2. The push-out bond strength values did not vary significantly considering the root segments (coronal, middle, and apical).
3. Er,Cr:YSGG laser application changed the surface morphology of the root posts studied, presenting larger defects and cracks on quartz and fiber compared to zirconia posts.

Clinical Relevance

Glass, quartz fiber or zirconia root posts conditioned with Er,Cr:YSGG laser did not benefit from increased push-out bond strength in the root canal.

Acknowledgement

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Conflict of interest

The authors did not have any commercial interest in any of the materials used in this study.

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Captions to tables and figures:

Tables:

Table 1. Brands, types, chemical compositions and manufacturers of the root posts and the luting cement used in this study.

Table 2. Mean push-out bond strengths (MPa), standard deviations of the experimental groups and significant differences. The same supercript letters for post sytem in each row, indicates no significant difference.

Table 3. Mean push-out bond strength (MPa) and standard deviations of root posts depending on the root sections. c: coronal; m: middle; a: apical. The same supercript letters for post sytem in each row, indicates no significant difference. See Table 1 for group abbreviations.

Figures:

Figs. 1a-f. SEM photomicrographs of D post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused ablation of the epoxy/methacrylate resin creating large defects and exposure of the quartz fibers as well as cracking of some fibers in 1b (L1 group) and 1c (L2 group) indicated by the arrow.

Figs. 2a-f. SEM photomicrographs of S post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused ablation of the epoxy/methacrylate resin creating large defects and exposure of the glass fibers as well as cracking of some fibers in **2b** (L1 group) and **2c** (L2 group) indicated by the arrow.

Figs. 3a-f. SEM photomicrographs of C post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused limited surface irregularities in 3**e** (L1 group) and 3**f** (L2 group) indicated by the arrow.

Tables:

Brand	**Type**	**Chemical composition**	**Manufacturer**
Snowpost (S)	Fiber post	ilica, zircon-glass fiber, epoxy resin matrix	GC Europe, Tokyo, Japan
DT Light (D)	Quartz post	rtz fiber, epoxy resin matrix	Ultradent, South Jordan, Utah, USA
Cosmopost (C)	Zirconia post	ZrO_2, HfO_2, Y_2O_3, Al_2O_3	Ivoclar, Vivadent, Schaan, Liechtenstein
Panavia F 2.0	Luting resin composite	Base: bis-GMA, UDMA, TEGDMA, fillers, ytterbium trifluoride, stabilizers, pigments, benzoyl peroxide	Kuraray, Noritake Dental Inc., Osaka, Japan

Table 1. Brands, types, chemical compositions and manufacturers of the root posts and the luting cement used in this study.

	D			C			S		
	L0 (n=25)	L1 (n=23)	L2 (n =23)	L0 (n=20)	L1 (n=21)	L2 (n=23)	L0 (n=21)	L1 (n=19)	L2 (n=26)
Mean push-out bond strength (MPa)± SD	28.3±16.8[a]	16.16±19.89[b]	8.24±9.26[b]	8.22±11.12[c]	12.52±18.34[c]	30.31±33.07[c]	43.89±35.76[d]	20.34±9.9[d]	26.14±18.45 [d]
p	<0.001			=0.158			=0.057		

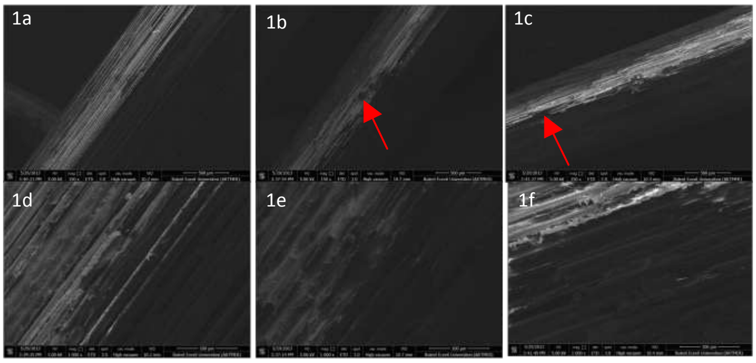
Table 2. Mean push-out bond strengths (MPa), standard deviations of the experimental groups and significant differences. The same supercript letters for post sytem in each row, indicates no significant difference.

	D			C			S		
	c (n=27)	**m** (n=24)	**a** (n=20)	**c** (n=25)	**m** (n=20)	**a** (n=19)	**c** (n=25)	**m** (n=20)	**a** (n=18)
Mean push-out bond strength (MPa)± SD	17.46±16.14^{a}	16.4±15.22^{a}	20.19±22.98^{a}	22.49±28.4^{b}	0.36±20.44 ^{b}	8,48±23,64^{b}	34.31±29.15^{c}	23.27±21.36^{c}	32.58±24.81^{c}
p	=0.977			=0.111			=0.114		

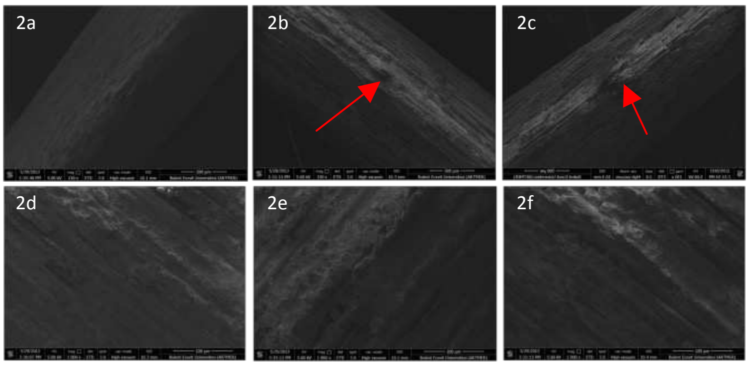
Table 3. Mean push-out bond strength (MPa) and standard deviations of root posts depending on the root sections. c: coronal; m: middle; a: apical.

The same supercript letters for post sytem in each row, indicates no significant difference. See Table 1 for group abbreviations.

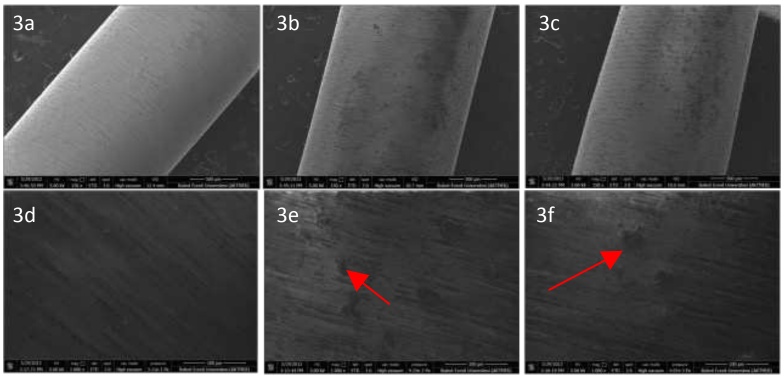
Figures:



Figs. 1a-f. SEM photomicrographs of D post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused ablation of the epoxy/methacrylate resin creating large defects and exposure of the quartz fibers as well as cracking of some fibers in 1b (L1 group) and 1c (L2 group) indicated by the arrow.



Figs. 2a-f. SEM photomicrographs of S post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused ablation of the epoxy/methacrylate resin creating large defects and exposure of the glass fibers as well as cracking of some fibers in 2b (L1 group) and 2c (L2 group) indicated by the arrow.



Figs. 3a-f. SEM photomicrographs of C post surface after L0, L1 and L2 conditioning at x150 and x1000. Note that Er,Cr:YSGG laser conditioning caused limited surface irregularities in 3e (L1 group) and 3f (L2 group) indicated by the arrow.